Ultraviolet Radiation for Water Treatment: Disinfection and Beyond

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UV Disinfection

An emerging technology

IS IT REALLY NEW?

UV Disinfection

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1910	First full scale UV disinfection system for pre-filtered water from the river Durance (Marseille, France)
1916	First full-scale application of UV in the US (Henderson, Kentucky)
1940s	With the invention of neon tubes, low pressure Hg lamps became available for UV disinfection
1970s	Discovery of DBPs from chemical disinfection, supported and promoted UV disinfection
1982	First large scale UV disinfection system in Canada (Tillsonburg, ON)
1998	Low UV dose was found effective for the inactivation of *Crypto* and *Giardia*

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UV Disinfection in Canada

1965 Ontario Water Resource Commission evaluated germicidal performance of UV on Humber River

1975 Canada Centre for Inland Waters evaluated UV disinfection as viable alternative

1979 Train derailment in Mississauga and major Cl_2 release increased impetus for alternative disinfectants

1999 More than 100 UV disinfection plants in operation in the province of Ontario

UV Disinfection

Presently

More than 6000 drinking water facilities use UV based disinfection

UV Disinfection Standards and Regulations

1989 The EPA Surface Water Treatment Rule (SWTR) did not indicate UV as Best Available Technology (BAT) for the inactivation of *Giardia*

2000 EPA started evaluating UV as a BAT for surface water disinfection

2006 EPA released the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)

Standards and Guidelines *(Atlantic Provinces)*

Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution, and Operation of Drinking Water Supply Systems

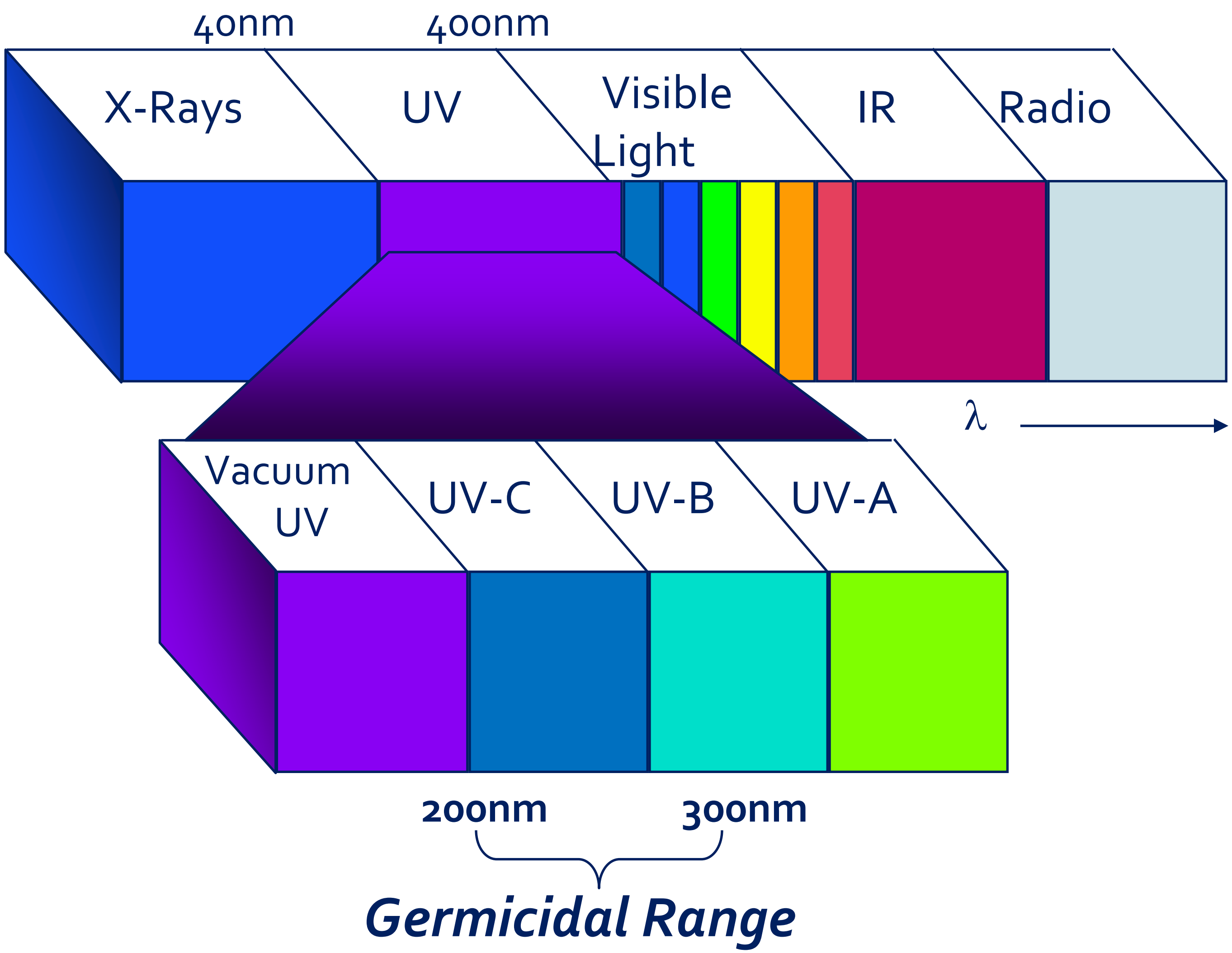
- For the four Atlantic Canada Provinces and coordinated by the Atlantic Canada Water Works Association
- *http://www.gov.ns.ca/enla/water/docs/watersupplyguidelines*
- *Section 4.6.2.2*

How does UV work

and

What does affect its performance?

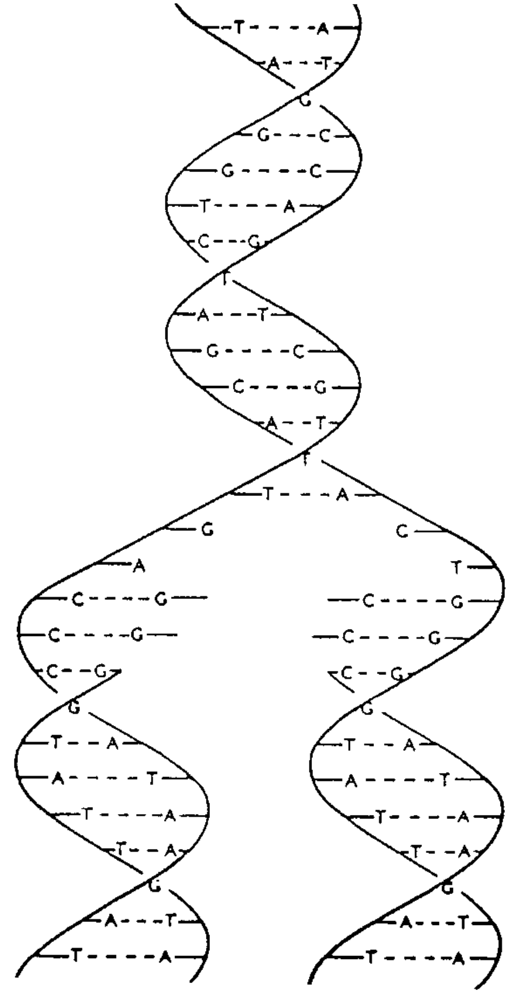
Electromagnetic Spectrum



DNA Structure and Replication

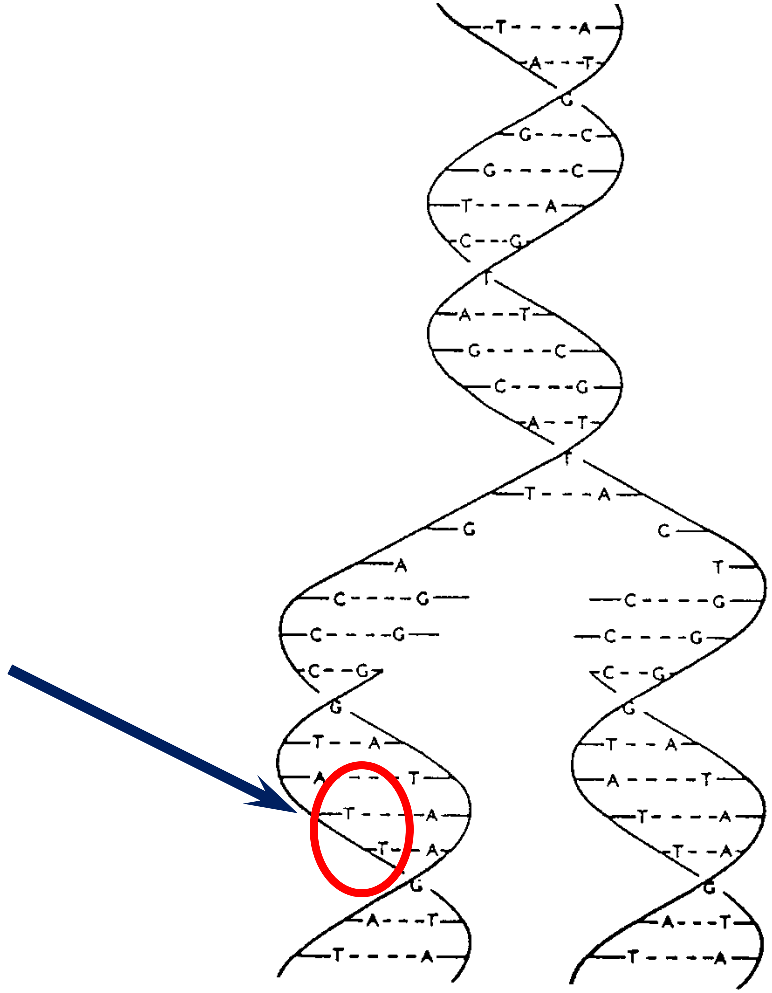
Parental DNA strands

Daughter DNA strands



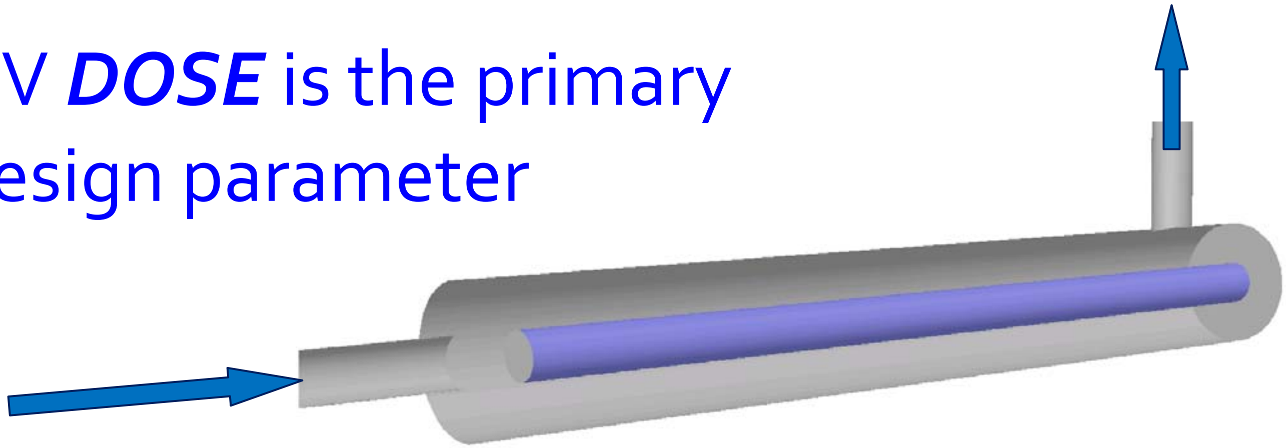
UV Damage to DNA

Dimerization of
Thymine nucleotides



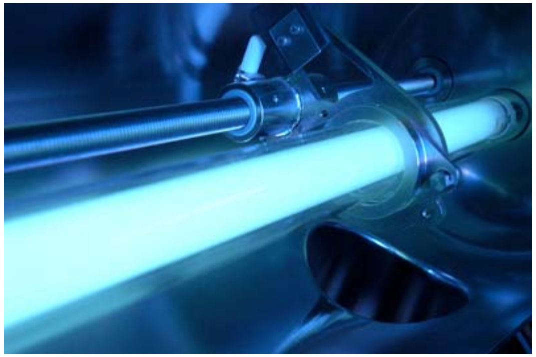
UV Disinfection

UV ***DOSE*** is the primary design parameter



UV ***DOSE*** is a product of Intensity and retention time

Intensity x Retention time = DOSE



Courtesy of Aquionics ***(www.aquionics.com)***

Key Factors in UV Disinfection

- UV lamp type
- Water quality
- Target organisms
- Reactor geometry and configuration

All are important parameters in determining and obtaining the required

MINIMUM UV DOSE

Key Factors in UV Disinfection

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Key Factors in UV Disinfection

Three most common lamp technologies used in water disinfection are:

- Low pressure (LP)
- Low pressure high output (LPHO)
- Medium pressure (MP)

Other UV lamps:

- Electrode less mercury vapor lamp
- LED lamp
- UV lasers
- Pulsed UV

Mercury Vapor UV Lamps

- Emit UV in the germicidal wavelength ranges
- UV is generated by applying a voltage across a gas mixture containing mercury vapor

Vapor pressure	Temperature	UV
Low (<1 torr)	Moderate (40°C)	Monochromatic (253.7 nm)
High (>300 torr)	High (600-900 °C)	Polychromatic

Mercury Vapor UV Lamps

Parameter	LP	LPHO	MP
Germicidal UV	253.7 (nm)	253.7 (nm)	Polychro-matic
Electrical input (W/cm)	0.5	1.5-10	50-250
Efficiency (%)	35-38	30-40	10-20
No. lamps required	High	Intermediate	Low
Complexity	Low	Moderate	Moderate

Source: *EPA's UV Disinfection Guidance Manual*

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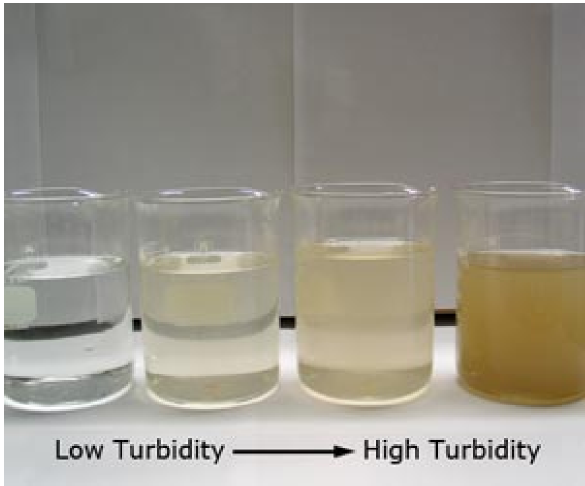
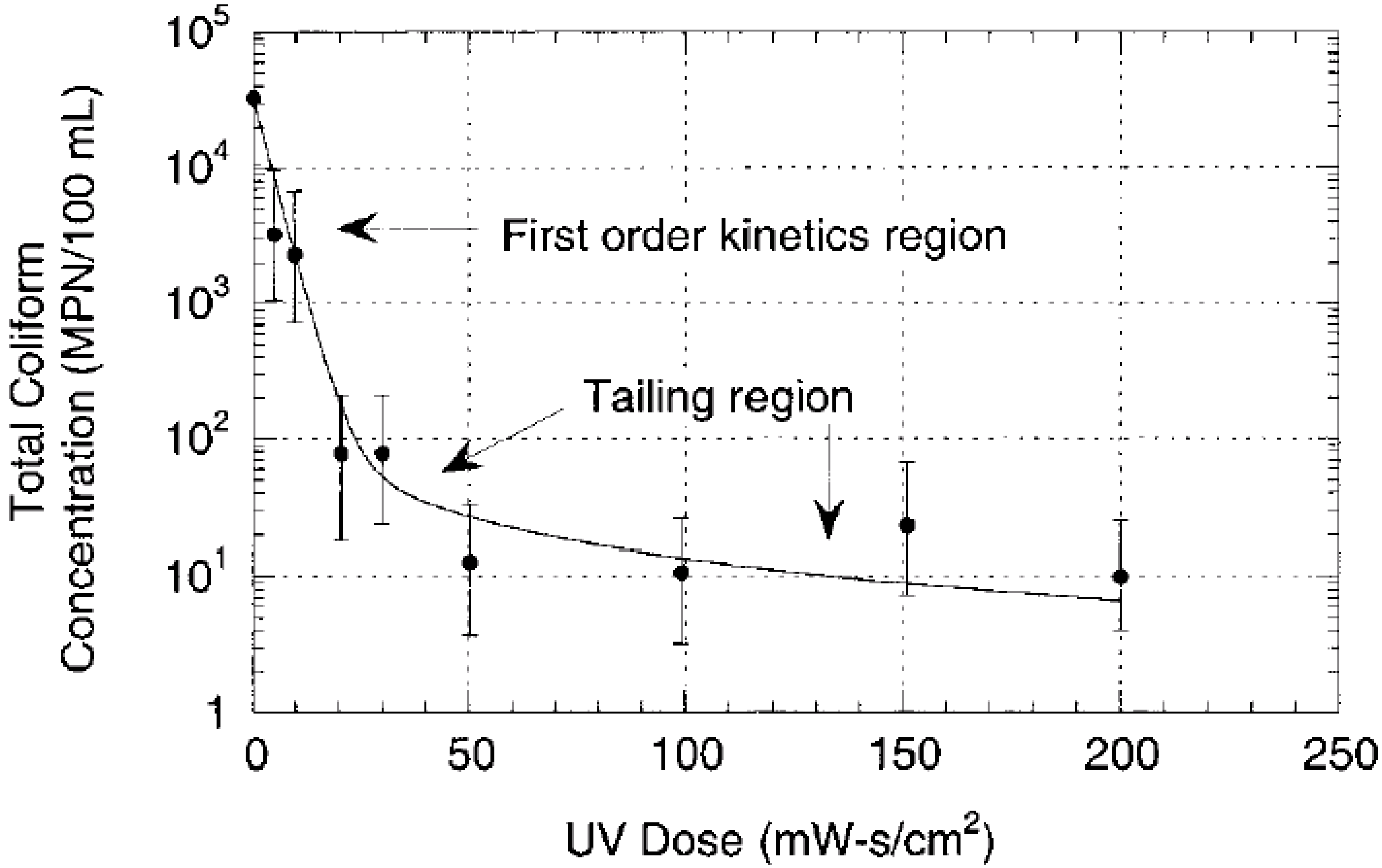
Water Quality Parameters



- Solids and suspended particles (turbidity and TSS)
- Dissolved organics and inorganic matters (TOC, NOM, iron, Ca, sulfites)
  - block or attenuate UV
  - cause fouling of the quartz and/or UV sensor
- Temperature

Effect of Particles



Typical response of Coliform bacteria to UV in wastewater (containing suspended solids)

UV Transmittance

Water	Typical UVT
Unfiltered surface water	70% - 95%
Filtered surface water	75% - 95%
Groundwater	80% - 95%
Membrane treated water	> 95%

- A 5% reduction in UVT translates in nearly doubling the UV reactor size (to maintain the same dose)
- Turbidity of < 5 NTU and TSS of < 10 ppm recommended
- For UVTs less than 85-90%, pretreatment is recommended

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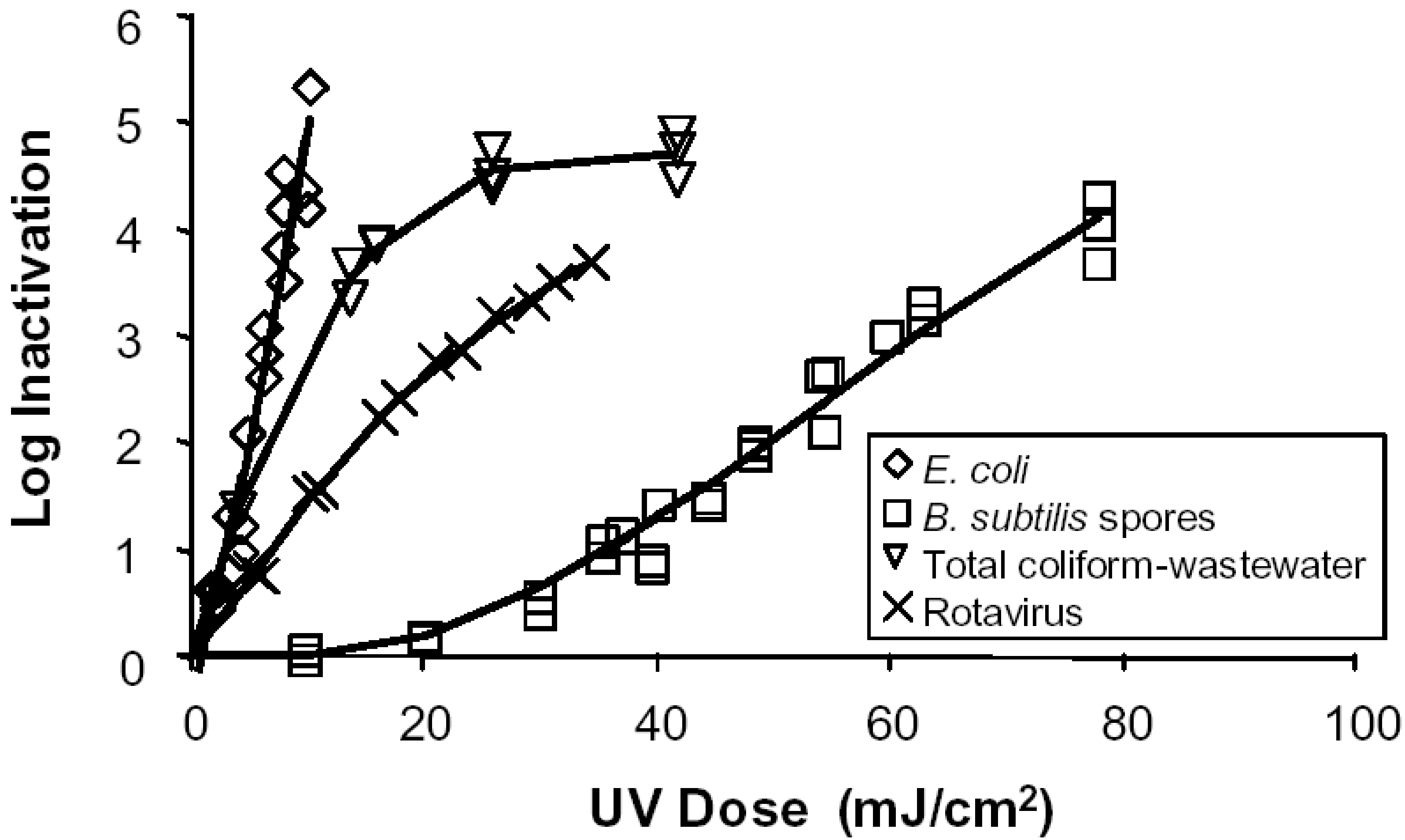
Target Organisms

UV germicidal efficiency for different organisms varies based on:

- Content of cytosine relative to thymine in the DNA
  - Quantum yield for thymine dimer formation is different from that of cytosine dimer formation
  - Thymine and cytosine have different absorbance spectra
- Specific characteristics of the DNA repair system
  - Viruses and bacteria have different repair mechanisms

Effect of Organisms



Source: *Chang et al. 1985*

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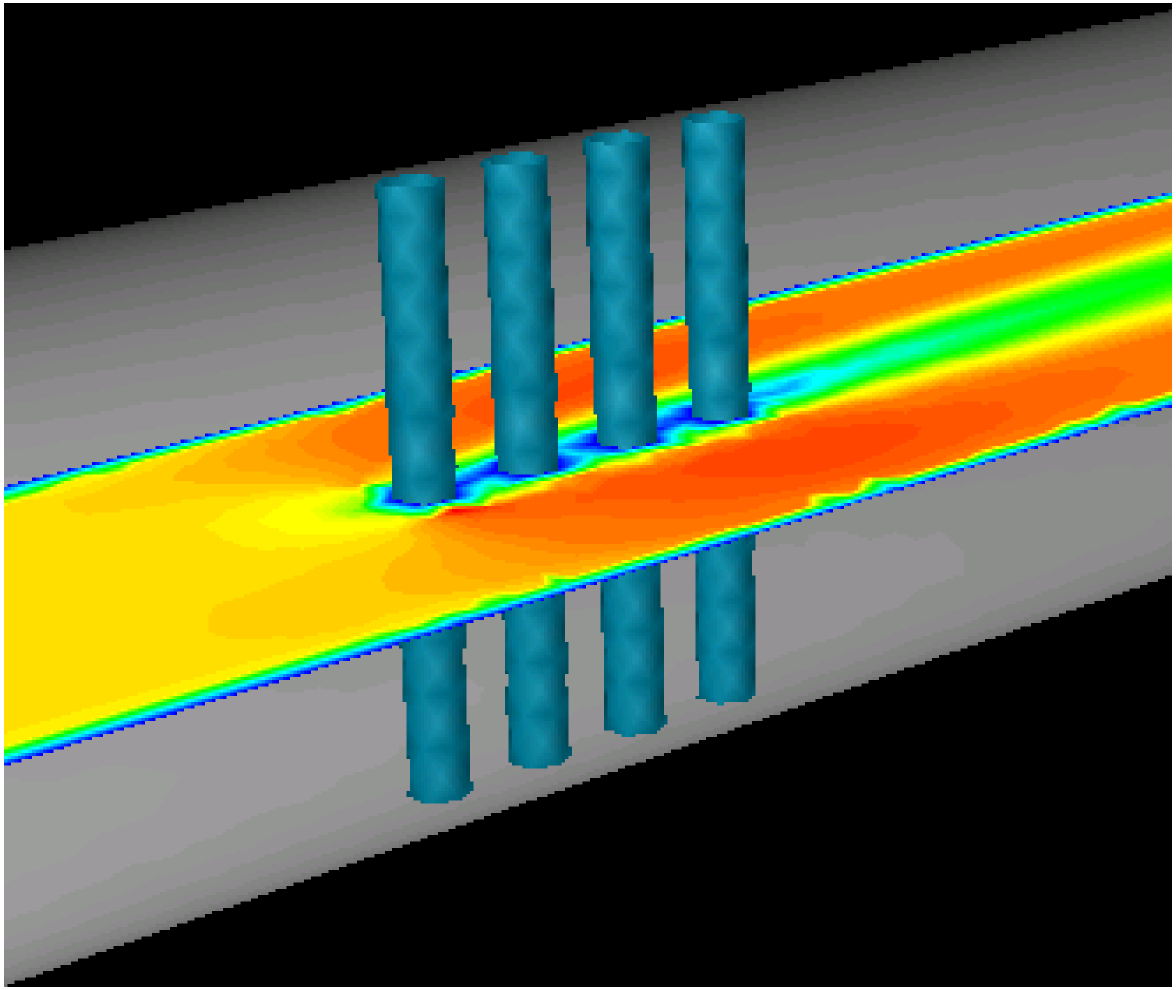
Reactor Configuration

- UV reactors are designed to optimize dose delivery
- Reactor configuration and hydrodynamics play important roles in design
  - Lamp placements
  - Inlet and outlet configurations
  - Baffles
  - Upstream flow conditions

Effect of Lamp Position



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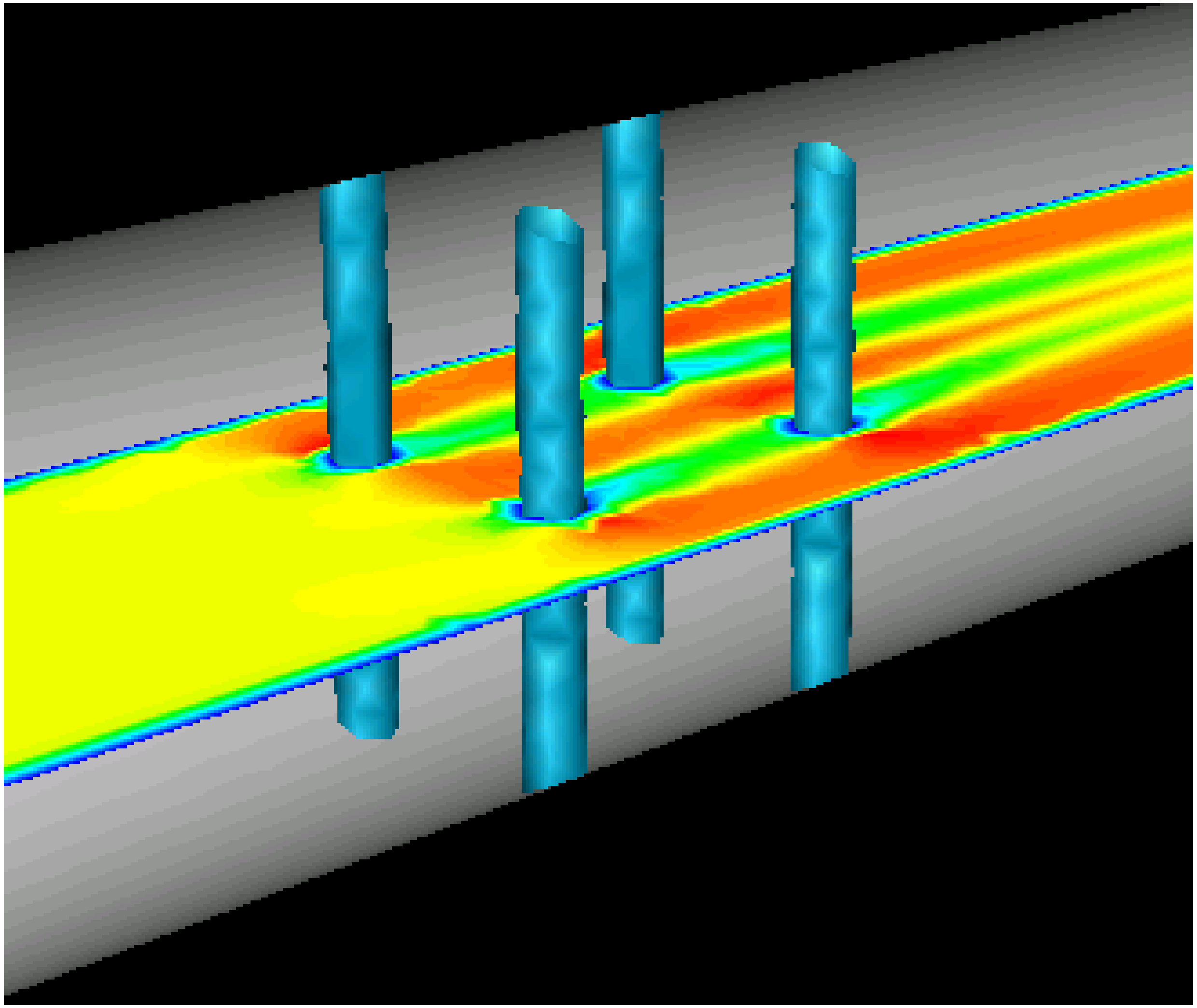

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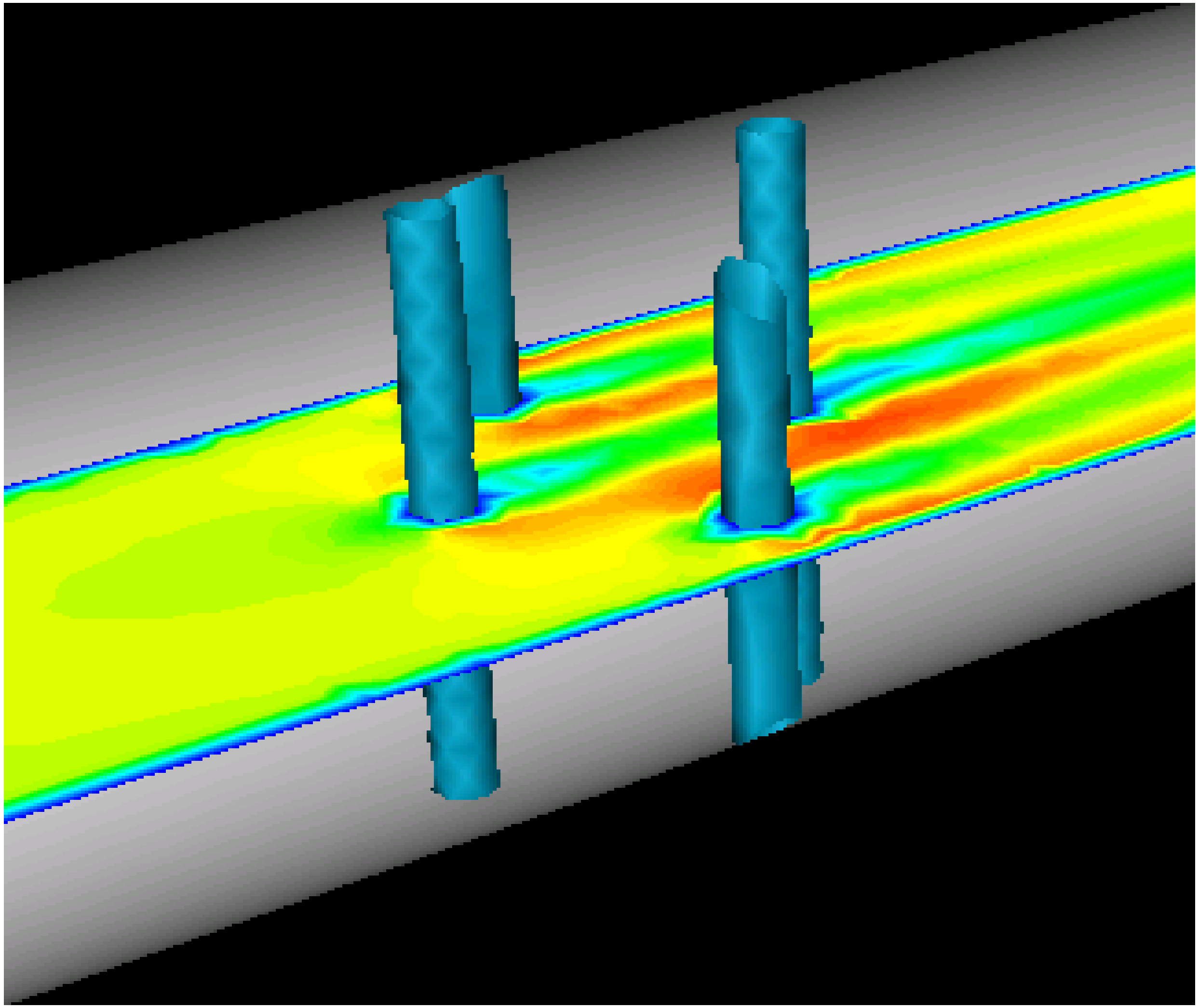

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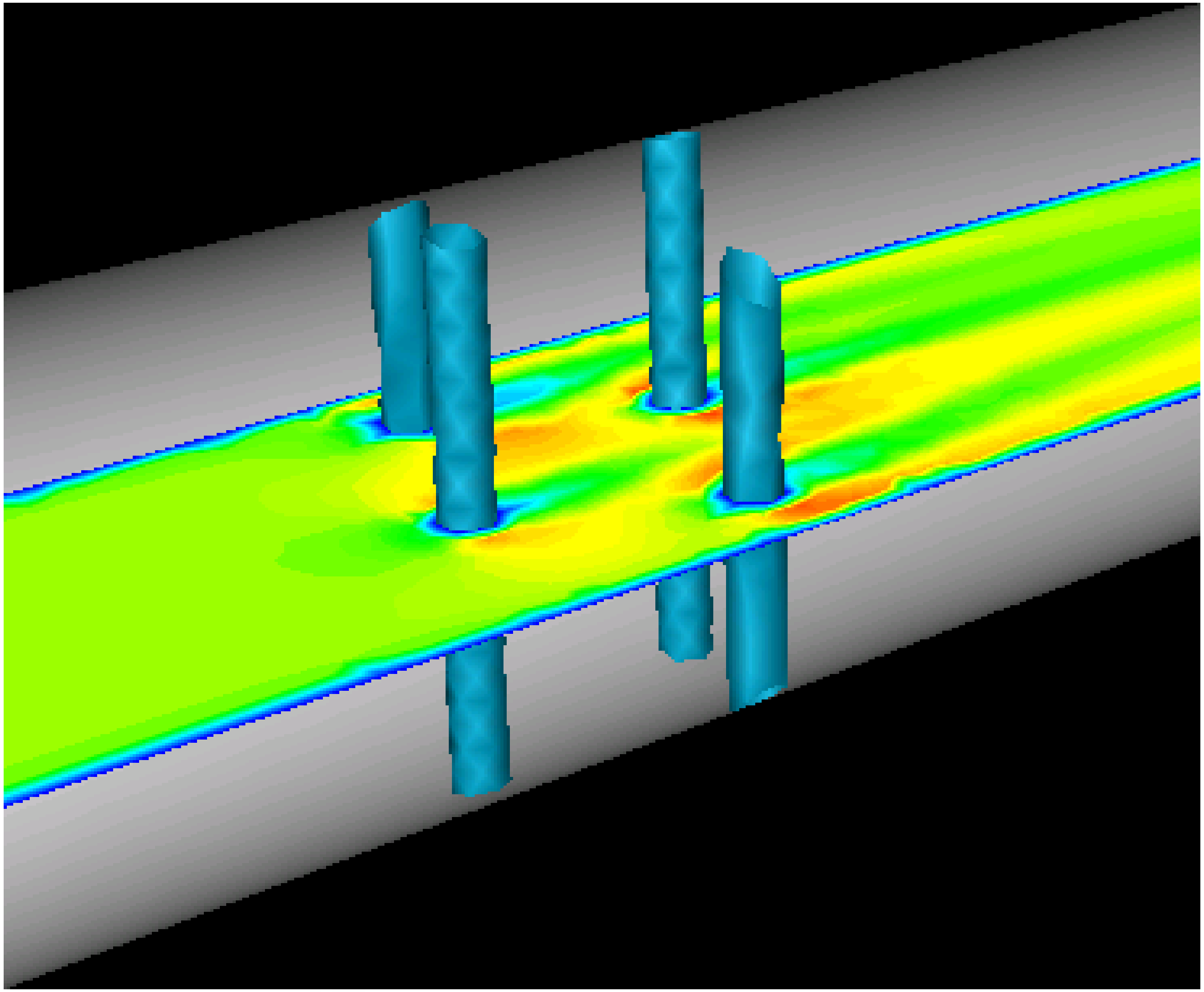


UV Reactors

UV8000™ (courtesy of Trojan Technologies)

UV Disinfection Systems

UV disinfection drinking water facility in Victoria
(Trojan Technologies)

UV Disinfection Systems

UV disinfection drinking water facility in Helsinki, Finland (Wedeco)

Design Guideline
(Section 4.6.2.2)

A number of considerations should be made when designing UV systems, among them being:

- The lowest transmittance of the supply to provide pathogen inactivation consistent with regulation
- A minimum 3 log inactivation of *Giardia*, *Cryptosporidium*, and *Viruses*
- A minimum of 50% redundancy
- Based on peak flow
- Pretreatment for turbidity reduction
- Confirmation of reactor validation

What is the cost of UV disinfection?

Case Study

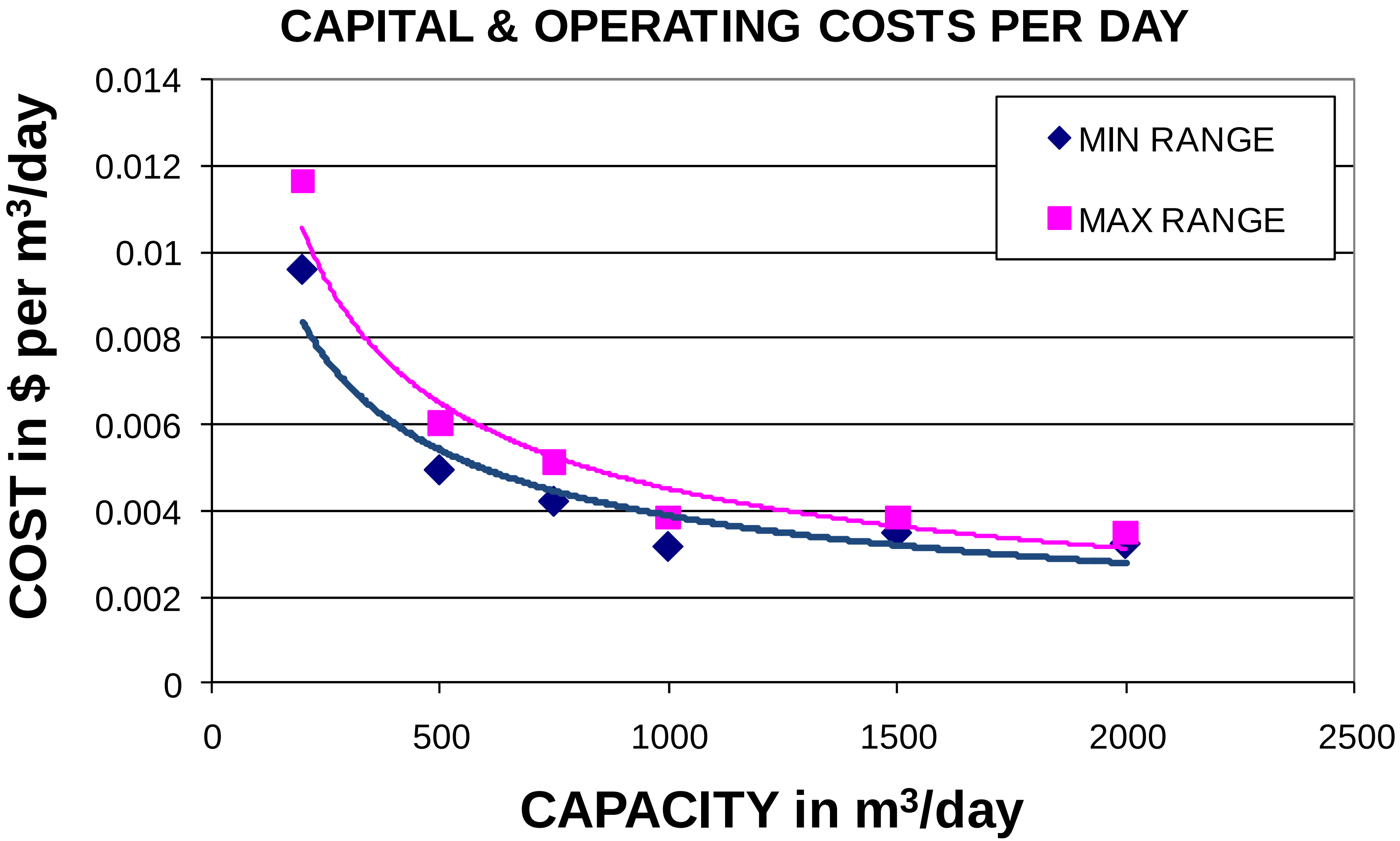
UVSWIFT®

by Trojan Technologies

Trojan UVSWIFT®

- UVSWIFT will inactivate bacteria and protozoa, with a dose of 40 mJ/cm^2
- For some source waters, UV may be sufficient (e.g., City of Victoria)
  - However, if turbidity is high settling and/or filtration and coagulation may also be needed

Trojan UVSWIFT®



Operational Considerations

Although UV is considered a *plug & play* system, some regular monitoring and maintenance are required:

- Proper O&M ensures the system operate according to specifications
- O&M requirements vary according to the system and manufacturer
- Visual inspection always provides much needed information

Sleeve and Sensor Fouling

By far, the most significant operational issue of the UV systems

Sleeve Fouling can affect UVT and disinfection performance

- Many parameters contribute to sleeve fouling (Lamp technology, water quality, flow, etc.)
  - e.g., iron content is often a significant factor in fouling
  - Hardness causes scaling on sleeve

Sleeve and Sensor Fouling

Cleaning can be done through chemical or mechanical wiping

- If automatic wipers are available, ensure they operate properly (e.g., check wiper cleaning fluid)
- For manual cleanings, manually clean sleeves and UV sensors

Is the application of UV limited to water disinfection?

UV-Based Oxidation Processes

UV photochemical oxidation processes for water treatment involve:

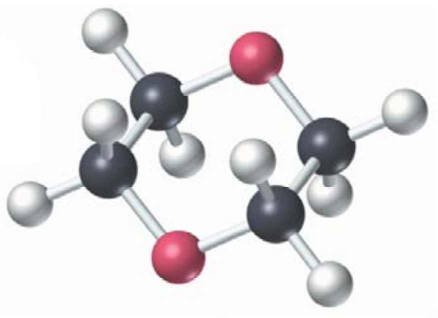
- Direct photolytic action of UV on dissolved matter in water (e.g. TOC, NOM)
- Photochemically assisted production of oxidants for removing harmful organic matter
- Photochemically assisted catalytic processes

UV-based Oxidation

(Commercial Installations)

Orange County Water District, CA, USA (2004)[a]	TrojanUVPhox™ NDMA; 1,4-dioxane
West Basin Municipal Water District, CA, USA (2005)[a]	TrojanUVPhox™ NDMA
Stockton, CA, USA (2001)[a]	TrojanUVPhox™ 1,4-dioxane
PWN Treatment Plant Andijk, Netherlands (2004)[b,c,d,e]	TrojanUVSwift™ ECT Pesticides
City of Cornwall, ON, Canada (2006)[a,f,g]	TrojanUVSwift™ ECT MIB & geosmin
Salt Lake City Department of Public Utilities, UT, USA (1998)[h]	Rayox™ PCE

TrojanUVPhox™ at Stockton



1,4-dioxane

TrojanUVSwift™ ECT at PWN

Calgon Rayox™

a – case studies provided by Trojan Technologies Inc. 2006; b – Kruithof et al. 2005; c – Martin et al. 2005; d – Stefan et al. 2005; e – Williams et al. 2005; f – Royce et al. 2005; g – Paradis et al. 2005; h - case study provided by Calgon Carbon Corporation 2005

Thank You!

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